Frontiers of shell-model description for atomic nuclei

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The nuclear shell model has been one of the most powerful tools for the study of nuclear structure. Once a suitable effective interaction is given, the shell model can describe various nuclear properties accurately and systematically in a unified framework, covering many nuclei in the model space of interest. It is useful not only for the analysis of experimental data, but also to predict unobserved properties of unstable nuclei.

In conventional shell model calculations, we use a complete set of many-body bases and diagonalize the Hamiltonian matrix. The applicability of such a method has been limited to relatively light nuclei or those near the closed shell, because of the explosive increase of the basis dimension. Owing to recent developments in computational facilities and numerical calculation techniques, most of the pf-shell nuclei are now in the scope of exact $0\hbar\omega$ calculations. The current frontier of such direct calculations is in the middle of the pf-shell ($A \sim 60$), where the maximum M-scheme dimension reaches to two billion.

On the other hand, various approximation methods have been developed to overcome the dimensionality problem. We have proposed the Monte Carlo shell model (MCSM)[1], which enables us to carry out the shell model calculations with reasonable accuracy in much larger model spaces and with more valence nucleons. The MCSM has been successfully applied to various problems such as the shell evolution in the exotic nuclei around $N = 20$, the spherical-deformed shape coexistence around ^{56}Ni, the unified description of pf-shell nuclei, and microscopic studies of the quadrupole collective motion in heavy nuclei.

The success of the shell model depends crucially on the choice of the effective interaction. The microscopic theory for deriving it from the nucleon-nucleon potential is insufficient especially for cases of many valence nucleons. Therefore it is needed to include the information form many-body data empirically for deriving a reliable effective interaction. In that sense, the experimental data and the shell model description can be developed complementarily, leading to our deeper understanding of various nuclear properties.

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